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THE INFLAMMABLE GASES IN MINE AIR

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ENGINEERING
ENGIN STORAGE

BY

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AND

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ERRATA.

The attention of the reader is called to the following corrections:

Page 4, 11th line from top, for "minus 0.2 or 0.3 per cent" read "minus 0.2 or 0.3 c. c."

Page 5, 7th line from bottom, for "0.2 per cent" read "0.2 c. c." Ninth and 10th lines from bottom, values for H_2 and CH_4 should be 1.93 and 21.94 per cent.

Page 6, 3d line from top, for "31.17 per cent CH_4 and 4.16 per cent C_2H_6" read "20.38 per cent CH_4 and 1.94 per cent C_2H_6." Eighth line from bottom, for "Chappins" read "Chappius."

Page 7, 9th and 10th lines from top, for "$2\times24.053=48.106$" read "$2\times24.051=48.102$." At bottom of page, values for CH_4 and N_2 should be 91.2 and 6.4 per cent instead of 90.6 and 7.0 per cent.

Page 8, in equation for partial pressure of carbon dioxide, the values should be $\left(\frac{27.90}{30.70}\right)\times760=690$ mm. instead of $\left(\frac{27.80}{30.90}\right)\times760=6$ mm., and the equation below should be $56.35-(2.014\times27.90)=0.16$ c. c. instead of $56.35-(2.014\times27.80)=0.16$ c. c. Line below equation for partial pressure of carbon dioxide should read "The true molecular volume of carbon dioxide at 690 mm." instead of "The true molecular volume of carbon dioxide at 686 mm."

Page 15, the last words in the title for figure 2 should read "and N_2" instead of "and N_2O."

Page 22, 20th line from top, for "10.9 per cent nitrogen" read "0.9 per cent nitrogen." Third line from bottom, and footnote, for "Howard" read "Coward."

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THE INFLAMMABLE GASES IN MINE AIR.

By George A. Burrell and Frank M. Seibert.

INTRODUCTION.

Much attention has been given in several European countries to the study of the inflammable gases found in coal mines, but not nearly as many analyses of gases from mines in the United States have been published. Methane is generally regarded as the inflammable constituent of fire damp, but it has been stated that hydrogen, ethylene, and members of the paraffin series higher than methane occur in some mines. It has been claimed, too, that carbon monoxide may be a constituent under conditions other than those well known to produce the gas, such as those attending mine fires and explosions.

That some of these gases may be formed as a result of a fire or explosion in a mine is granted, for the reactions that occur during fires and explosions are known to produce them, but the authors believe, as a result of their experiments, that ethylene, hydrogen, carbon monoxide, or ethane seldom occurs, even in very small quantities, in the air of American coal mines that are operating under normal conditions.

Samples of mine air have been obtained from many mines, in the main returns, splits, and entries, in places where the air was moving, and also in places where the air was still, as at working faces, cavities in the roof, in the goave, and in sealed inclosures. In addition, samples have been collected from parts of mines that were on fire and from mines shortly after explosions had occurred. Consequently, an excellent opportunity has been afforded to study mine gases that have accumulated under many different conditions. Some results of this study are presented in the following paper which is published by the Bureau of Mines as a contribution to a better knowledge of the causes of mine explosions.

INFLAMMABLE GASES IN NORMAL MINE AIR.

If other combustible gases than methane are present under normal conditions of mine operation, then the fact should be made known, because ethane, hydrogen, ethylene, and carbon monoxide give to mine-gas mixtures properties different from those of methane alone. Ethane, for instance, has a lower explosive limit and ignition tem-

perature than methane; hydrogen and ethylene also have lower ignition temperatures and wider explosive ranges, and carbon monoxide is harmful in extremely small proportions.

ACCURACY OF ANALYTICAL METHODS.

In analytical work performed by the authors particular attention has been paid to methods of examination, and most samples have been examined in duplicate in order to make sure that faulty analytical work would not lead to wrong conclusions. That faulty methods may lead to erroneous results is obvious. If a technical gas-analysis apparatus is used in which the usual experimental error of plus or minus 0.2 or 0.3 per cent is not avoided, the resultant error becomes serious as regards exact work.

To show the accuracy demanded in examining mine gases, the following analytical results are given. A mine atmosphere of this composition was recently examined at the bureau's laboratory:

Analysis of a mine atmosphere.

	Per cent.
CO_2	7.07
O_2	1.20
CO	.00
CH_4	28.22
N_2	63.51

The following calculations show the procedure adopted in determining the methane when the slow-combustion method of burning the methane was used:

	C. c.
Volume of sample taken for analysis	100.00
Volume after absorption of CO_2	92.93
CO_2 found	7.07
Volume after absorption of O_2	91.73
O_2 found	1.20
Volume of sample taken for combustion	45.86
O_2 added for combustion	54 14
Total volume for combustion	100.00
Volume after combustion	71.78
Contraction due to combustion	28.22
Volume after absorption of CO_2	57.67
CO_2 produced by combustion	14.11

A duplicate analysis in which a smaller proportion of the sample was taken for the analysis gave the following results:

Analysis of a mine atmosphere.

	Per cent.
CO_2	7.07
O_2	1.20
CO	.00
CH_4	28.33
N_2	63.40

The calculations follow:

	C. c.
Volume of sample taken	41.65
Volume after absorption of CO_2	38.70
CO_2 found	2.95
Volume after absorption of O_2	38.20
O_2 found	.50
Volume taken for combustion	38.20
O_2 added for combustion	68.55
Total volume for combustion	106.75
Volume after burning	83.20
Contraction due to burning	23.55
Volume after absorption of CO_2	71.40
CO_2 produced by combustion	11.80

The record of a typical analysis by the explosion method follows. The analysis is hypothetical and is presented simply to show the errors introduced by small variations in burette readings.

	C. c.
Volume taken for analysis	100.00
Volume after absorption of CO_2	92.93
CO_2 found	7.07
Volume after absorption of O_2	91.73
O_2 found	1.20
Volume taken for explosion	31.77
O_2 added for explosion	68.23
Total	100.00
Volume after explosion	84.00
Contraction due to explosion	16.00
Volume after absorption of CO_2	76.00
CO_2 produced by combustion	8.00

In the last analysis an experimental error of 0.2 c. c. in reading the gas volume after combustion would make this reading 83.8 c. c. An experimental error of 0.2 c. c. in reading the gas volume after the final carbon dioxide absorption would make the reading 76.2. The contraction due to combustion would then become 16.2 c. c., and the volume of carbon dioxide would become 7.6 c. c. Hydrogen and methane, if calculated from these data and figured to a percentage basis, would be

	Per cent.
H_2	1.19
CH_4	26.32

It will be seen that if only a part of the residual gas is taken for the analysis and if an error of 0.2 per cent is made in two burette readings, then the calculation will indicate considerable hydrogen.

An experimental error of plus 0.2 per cent made in reading the gas volume after combustion would result in an apparent reading of 84.2 c. c. An experimental error of 0.2 c. c. made in reading the gas volume after the carbon dioxide absorption would result in an apparent reading of 75.8. The contraction in volume and carbon

dioxide produced by the explosion then become 15.8 c. c. and 8.4 c. c., respectively, and if the calculation is made to methane and ethane the results become 31.17 per cent CH_4 and 4.16 per cent C_2H_6.

ERRORS DUE TO THE ASSUMPTION THAT THE MOLECULAR VOLUMES OF ALL GASES ARE ALIKE.

Exact specific-gravity determinations have shown that the molecular volumes of all gases are not alike, and as a consequence some gas analyses may be in error if Avogadro's theory be assumed.

Below are given the theoretical and observed specific-gravity determinations (air = 1) at 0° C. and at 760 mm. pressure of those gases that enter into reaction when methane is burned in complete combustion with oxygen.

Comparison of theoretical and observed specific-gravity determinations.

Gas.	Theoretical density.	Observed density.	Observer.	Theoretical / Observed.
Oxygen	1.1055	1.1053	Rayleigh	1.000
Nitrogen	.9680	.9674	do	1.000
Methane	.5539	.5545	Baumé and Perrot	.999
Carbon dioxide	1.5201	1.5291	Rayleigh	.994

The molecular volumes of oxygen, nitrogen, and methane are close enough to the theoretical, but considerable variation is noted in the theoretical and observed molecular volumes of carbon dioxide.

The weight of a liter of carbon dioxide at 0° C. and 760 mm. pressure is 1.9769 grams according to Rayleigh [a] and 1.9768 grams according to Guye and Pintza.[b]

Then 22.412 liters of carbon dioxide weighs 22.412 × 1.9768 = 44.304 grams at 0° C. and 760 mm. pressure. The coefficient of expansion of carbon dioxide between 0° and 20°, as determined by Chappins,[c] is 0.003736.

Then 22.412 × 0.003736 × 20 = 1.6746 liters; 1.6746 + 22.412 = 24.087 liters, the volume occupied by 44.304 grams of carbon dioxide when the temperature has been raised to 20° C. from 0° C. at 760 mm. pressure. A gram-molecule of carbon dioxide equals 44.003 grams and occupies at 0° C. and 760 mm. pressure:

$$\frac{44.003}{44.305} \times 24.087 = 23.923 \text{ liters.}$$

According to the gas laws, at 20° C. and 760 mm. pressure the volume becomes

$$22.412 \times \frac{293}{273} = 24.051 \text{ liters.}$$

[a] Rayleigh. On the densities of carbonic oxide, carbonic anhydride, and nitrous oxide. Proc. Roy. Soc., vol. 62, 1897, p. 204.

[b] Guye, P. A., and Pintza, A., Determination des densités des gay anhydride carbonique, ammoniac et protoxyde d'ayote. Mém. Soc. phys. et hist. nat. de Genève, vol. 35, 1908, p. 569.

[c] Bull. Inst. poids. et mes., vol. 13, 1903, p. 190.

At 20° C. and 760 mm. pressure then a gram-molecule of carbon dioxide occupies a volume that is 0.54 per cent less than the volume according to the gas laws. The true molecular volume is therefore 0.9946 of the volume according to the gas laws.

Rayleigh [a] found that at 15° C. 1 volume CO_2 × 1 atmosphere = 1.00279 (2 volumes CO_2 × ½ atmosphere); then 23.923 liters of carbon dioxide at 20° C. and 760 mm. pressure when subjected to a pressure of 380 mm. becomes 47.846 × 1.00279 = 47.980 liters. A gram-molecule of carbon dioxide should occupy 2 × 24.053 = 48.106 liters, which is 0.26 per cent below the true volume. The true molecular volume at 20° C. and 380 mm. pressure is, therefore, 0.9974 per cent of the volume according to the gas laws; 0.26 per cent is approximately one-half of 0.54 per cent. A graph plotted through three points, 0, 380, and 760 mm. pressure, results in a straight line. Correct molecular volumes to use in the calculation of analyses at temperatures near 20° C. and at different partial pressures of the carbon dioxide follow:

True molecular volume of carbon dioxide at different partial pressures.

Mm.	Volume.
100	0.9993
200	.9986
300	.9980
400	.9972
500	.9965
600	.9958
700	.9951
760	.9946

By inserting the proper value for the molecular volumes of methane and carbon dioxide in the equation

$$CH_4+2O_2=CO_2+2H_2O$$

the latter becomes

$$0.999\ CH_4+2O_2=0.995\ CO_2+2H_2O$$

This equation is to be used when gas-analysis determinations are made at a temperature of about 20° C. and the carbon dioxide produced by combustion in the mixture being analyzed constitutes between 80 and 100 per cent of the volume found after combustion. For other partial pressures of carbon dioxide, the true molecular volumes can be obtained from the table.

A mine gas mixture having the following composition was recently analyzed by the authors:

Analysis of a mine gas mixture.

Gas.	Per cent.
CO_2	0.30
O_2	2.10
CH_4	90.60
N_2	7.00

[a] Rayleigh. On the compressibility of gases between one atmosphere and half an atmosphere of pressure. Trans. Roy. Soc., vol. 204, 1905, p. 360

The observed data as found in the actual determination follow:

	C. c.
Volume taken for analysis	30.70
Volume after absorption of CO_2	30.70
Volume after absorption of O_2	30.05
Volume taken for combustion	30.05
O_2 added for combustion	57.20
Total volume for combustion	87.25
Volume after combustion	30.90
Contraction due to combustion	56.35
Volume after absorption of CO_2	3.00
CO_2 produced by combustion	27.90

According to the reaction

$$CH_4+2O_2=CO_2+2H_2O$$

the contraction should be just twice the carbon dioxide. It will be noticed, however, that there is a difference of

$$56.35-2(27.90)=0.55 \text{ c. c.}$$

Were a calculation of methane and hydrogen made from the observed results just as they were recorded in the analyses, using the well-known formulas in which $CH_4=CO_2$ and $H_2=\frac{2}{3}$ [(contraction) $-2CO_2$], one would find that the $CH_4=90.88$ per cent and $H_2=1.2$ per cent.

Carbon dioxide in the mixture after combustion had a partial pressure of

$$\left(\frac{27.80}{30.90}\right)\times 760=6 \text{ mm.}$$

The true molecular volume of carbon dioxide at 686 mm. and 20° C. is 0.995. The equation becomes

$$0.999CH_4+2O_2=0.995CO_2+2H_2O$$

According to the true equation there will be a difference of

$$56.35-(2.014\times 27.80)=0.16 \text{ c. c.}$$

a value that is only a little greater than the error of experimentation.

Aside from errors that creep into work during a combustion analysis—unless exact work be performed in using bromine water, fuming sulphuric acid, or cuprous chloride solution—poor manipulation, misuse of solutions, or errors inherent in the apparatus will lead to the recording of contractions in volumes when ethylene or carbon monoxide is not present.

WORK AND COMMENTS OF OTHERS ON MINE GASES AND GASES EXTRACTED FROM COAL AT ORDINARY TEMPERATURES.

Brunck[a] makes the following comment: "The chemical composition of the gases of various blowers has led to the supposition that mine gases contain in addition to methane, higher hydrocarbons, such as

[a] The investigation of mine air, edited by C. Le N. Foster and J. S. Haldane, 1905, p. 17.

ethane, C_2H_6, and propane, C_3H_8, but up to the present time not one of them has been recognized with certainty." Brunck further states that hydrogen is rarely found in coal, but has been identified as a constituent of the gas of many blowers.

Leon Poussigue [a] states that the combustible part of fire damp is composed principally of methane; that in some there is a very small proportion of hydrogen (never more than 1 per cent, as has been proved by direct analysis), but never any ethane.

Beard [b] states that olefiant gas (ethylene) renders fire damp easier to ignite and increases its explosive force:

> In mining parlance, it makes the gas sharp, by which is meant the gas is fresh from the strata and more active, agitates the flame more and obstructs the formation of the flame cap, which is always difficult to observe in sharp gas. Fresh feeder gas as it issues from the strata and before it is diluted with mine air is generally sharp. The effect of the presence of the olefiant gas is to sharpen fire damp and increase the danger from this cause.

Redmayne [c] says:

> The chief constituent of fire damp or marsh gas or simply "gas," as it is called, is methane or light carbureted hydrogen, CH_4, but it is not entirely composed of this explosive gas. "Pure" fire damp would be composed entirely of methane, but all analyses that have been carried out so far have shown it to contain small quantities of other gases. The purer the fire damp the more highly explosive will be the mixture it forms with air.

Stirling and Cadman [d] collected a sample of mine gas from the Bellevue mine, Canada, which Dr. Wheeler, chemist for the British Coal Dust Commission, analyzed and reported as containing the following constituents:

Analysis of gas from Bellevue mine, Canada.

Constituent.	Per cent.
CO_2	0.15
O_2	19.30
CH_4	4.35
C_2H_6	.30
N_2	75.90

The authors came to the conclusion that fire damp in the mine was ignited by the fall of a piece of roof and attach significance to the fact that ethane was present in the fire damp. They call attention to the fact that ethane in fire damp gives the latter a lower ignition temperature than if methane were the only combustible constituent.

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[a] The investigation of mine air, edited by C. Le N. Foster and J. S. Haldane, 1905, p. 77.

[b] Beard J. T. Mine gases and explosions, 1908, p. 104.

[c] Redmayne, R. A. S., The ventilation of mines: Modern practice in coal mining, vol. 4, 1911, p. 32.

[d] Stirling, J. T., and Cadman, John, The Bellevue explosion, Alberta, Canada: Coll. Guard., vol. 104, Sept. 13, 1912, p. 534.

Haldane [a] reported the results of analyses made by him of six samples of mine gases, containing from 0.88 per cent to 4.52 per cent CH_4. Combustible gases other than methane were not found.

In another investigation Haldane [b] analyzed eight samples of mine gas in which the only combustible gas found was methane.

Gray [c] analyzed 85 samples of mine air from different coal mines in Scotland and reported only methane as the combustible gas. He states that fire damp in the air of coal mines seems to consist entirely of methane in all of the samples examined, but that in the case of samples from some of the shale mines the analytical figures pointed to the probable presence of traces of some other gaseous carbon compound, but it was impossible to estimate these minute quantities by the methods of gas analysis, so only methane was reported.

Von Meyer [d] examined a number of German coals and the gases they contained. The gases from eight of the samples of coal were found to contain ethane, and in three of these the proportion of ethane was nearly equal to, or was even greater than, that of methane. None of the samples that gave ethane was from freshly mined coal and two of the coals had been exposed to the weather for five years.

Thomas [e] found that the gases obtained from 13 blowers and bore holes in the South Wales Basin consisted almost entirely of methane. The latter varied from 94.78 per cent to 97.65 per cent in 12 of the samples. There were in some instances indications of traces of a hydrocarbon other than methane. Thomas believed this to be ethane, but the proportion was so minute that the gas was calculated as methane. In one case, however, he reported 0.9 per cent ethane.

Schloseing [f] made an examination of 16 samples of fire damp from typical French mines with the object of determining whether methane was the only inflammable gas present, and concluded that only three of the samples contained an appreciable quantity of a combustible gas other than methane. He accounted for these by assuming that a small percentage (2 to 4 per cent) of ethane was present. He finally concluded that the combustible portion of fire damp might be considered in practice to consist simply of methane, although it sometimes happens to contain a small but sensible proportion of some other hydrocarbon.

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[a] Haldane, J. S., Investigations on the nature and sources of the suffocative gas met with in wells, together with further observations of the black damp of coal mines: Trans. Fed. Inst. Min. Eng., vol. 11, 1895–96, p. 265.

[b] Haldane, J. S., Investigation of the occurrence, properties, and composition of black damp: Trans. Fed. Inst. Min. Eng., vol. 8, 1894–95, p. 549.

[c] Gray, Thomas, Analyses of samples of air from representative mines in Scotland: Trans. Fed. Inst. Min. Eng., vol. 39, 1909–10, p. 305.

[d] Von Meyer, E., Jour. Prakt. Chem., vol. 5, 1872, pp. 144 and 407, and vol. 6, 1872, p. 360.

[e] Thomas, J. W., Gases inclosed in coals from South Wales Basin and the gases evolved by blowers and by boring into the coal itself: Jour. Chem. Soc., vol. 28, pt. 2, 1875, p. 820.

[f] Schloseing, M., Composition of fire damp: Abs. Trans. Fed. Inst. Min. Eng., vol. 11, 1896, p. 611.

Beard [a] published analyses of blower and bore-hole gas which contain only methane as the combustible gas. The samples contained from 77.69 per cent to 99.10 per cent methane.

The Colliery Guardian [b] makes the following statement:

> There are many facts that lead to the conclusion that fire damp differs considerably from artificially prepared methane, and we would certainly hesitate to assume that any sample of fire damp is methane alone.

Franke [c] gives analyses of mine gases in which only carbon dioxide and methane were found.

Trowbridge [d] found 0.7 and 0.9 per cent of carbon monoxide in gases he extracted from two samples of coal by means of a vacuum at ordinary temperatures. In eight other samples of gas that he extracted from coal at ordinary temperatures he found no carbon monoxide. He did not find ethylene nor did he report hydrogen. He stated that the combustible gas yielded by dust formed in screening the coal gives results that are most easily interpreted as indicating the presence of hydrocarbons of the paraffin series other than methane.

Burgess and Wheeler [e] make the following statement regarding the presence of paraffin hydrocarbons in mine gas:

> Moreover, we had reason to believe that "fire damp" should not be regarded as consisting of pure methane or methane diluted with a greater or lesser quantity of air, but that in many samples other hydrocarbons are present in appreciable (and by no means negligible) quantities. * * * Further, when it is remembered that the major portion of the inflammable gases that find their way into the ventilating current of coal mines issues from minute fissures in the coal, and that the gases can be extracted from coal at the ordinary temperature, either by exhaustion or by simply crushing, contain not only ethane but higher members of the paraffin series of hydrocarbons, it will be seen that the limits of inflammability of every sample of fire damp must not be regarded as identical with those of any one particular sample.

These considerations prompted Burgess and Wheeler to determine the low limit of inflammation of the higher members of the paraffin series of hydrocarbons when mixed with air, as well as the low limit of methane.

Chamberlin [f] reports 29 analyses made by him of mine gases collected in the Monongah mine, Monongah, W. Va., the Naomi mine near Bellevernon, Pa., and the Darr mine, Jacobs Creek, Pa. The samples were collected in these mines after a fair state of ventilation had been established following explosions. He reports from 0.05 to 0.61 per cent carbon monoxide in 23 samples. Fourteen of the samples were analyzed by means of Hempel's technical gas-analysis apparatus.

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[a] Beard, J. T., Mine gases and explosions, 1908, p. 103.

[b] Col. Guard., vol. 103, Apr. 26, 1912, p. 846.

[c] Franke, J., Jour. Prakt. Chem. (2) vol. 37, 1888, pp. 91 and 113.

[d] Trowbridge, F. G., Jour. Soc. Chem. Ind., vol. 25, 1906, p. 1129.

[e] Burgess, M. J., and Wheeler, R. V., The lower limit of inflammation of mixtures of the paraffin hydrocarbons with air: Trans. Chem. Soc., vol. 99, 1911, p. 2015.

[f] Chamberlin, R. T., Explosive mine gases and dusts: U. S. Geol. Survey Bull. 383, 1909, pp. 8–9.

In 10 of these 14 samples he reports carbon monoxide in quantities lower than 0.1 per cent. The other samples were analyzed by means of the more accurate Bone and Wheeler apparatus. These determinations were made by means of absorption in cuprous chloride. Although it is true that carbon monoxide may often linger in the mine atmosphere after explosions, yet the authors believe that much reliance can not be placed upon the Hempel technical apparatus for the determination of proportions of carbon monoxide less than 0.1 per cent.

Chamberlin also reports analyses of 15 samples of gas collected from bottles that had been evacuated and into which small lump coal had been introduced. In 8 of these samples he found carbon monoxide and olefin hydrocarbons in combined proportions, in one sample amounting to as much as 1.13 per cent. In 5 of the 15 samples he reported olefin hydrocarbons individually in quantities ranging from 0.29 per cent to 0.87 per cent. In 1 sample of the 15 he found 0.22 per cent of carbon monoxide. He further states that in nearly every analysis he found at least one other member of the paraffin series of hydrocarbons, and that the proportions of methane present varied from a trace to four parts of C_2H_6 in each 100 parts of CH_4, and that in several tests the explosion of anthracite gas instead of indicating higher paraffins suggested the presence of a small amount of hydrogen.

In 6 other samples of gas escaping from crushed coal bottled in a vacuum Chamberlin also found carbon monoxide, olefin hydrocarbons, ethane, and hydrogen. At the end of 14 weeks the bottled coal gave off a gas that contained 13.35 per cent of combined carbon monoxide and ethylene. In one sample of feeder gas Chamberlin found 0.82 per cent hydrogen, and in each of 5 samples of feeder gas he found small quantities of carbon monoxide and ethylene.

Redmayne [a] quotes the Prussian Fire Damp Commission as publishing analyses made by Dr. Schondorff in 1882–1884 of fire damp containing from none to 5.84 per cent hydrogen and from none to 37.62 per cent ethane.

He also quotes Dr. Poleck as finding 2.89 and 3.99 per cent ethane and 1.87 per cent and no carbon monoxide in two samples of mine gas taken from a dip drift in the Glückhilf colliery at Waldenburg.

Porter and Ovitz,[b] in their work on the gases given off by coals at ordinary temperature, report no hydrogen, olefin hydrocarbons, higher paraffin hydrocarbons, or carbon monoxide as the result of the examination of nine coals taken from six States. They state that their error of experimentation was 0.2 per cent

[a] Redmayne, R. A. S., The ventilation of mines: Modern practice in coal mining, vol. 4, 1911, pp. 34 and 35.

[b] Porter, H. C., and Ovitz, F. K., The escape of gas from coal. Technical Paper 2, Bureau of Mines, 1911. 44 pp.

Bowen and French [a] grant that coal gas may be more sensitive to ignition than methane, but in part justify its use for their tests of safety devices for electrical mine equipment by attempting to show that hydrogen and ethane are believed to be constituents of mine air.

Parr and Barker [b] analyzed 67 samples of gases extracted from coal at ordinary temperatures and reported no combustible gas other than methane.

Harger [c] states that the assumption that the inflammable gas of fire damp is methane is incorrect. He reports the combustion data obtained from the analysis of 20 samples of mine air which indicate the presence of combustible gases other than methane.

Work performed by other investigators shows that combustible gases other than methane are given off by coal at temperatures above normal. This report concerns itself with the gases that escape at ordinary temperatures.

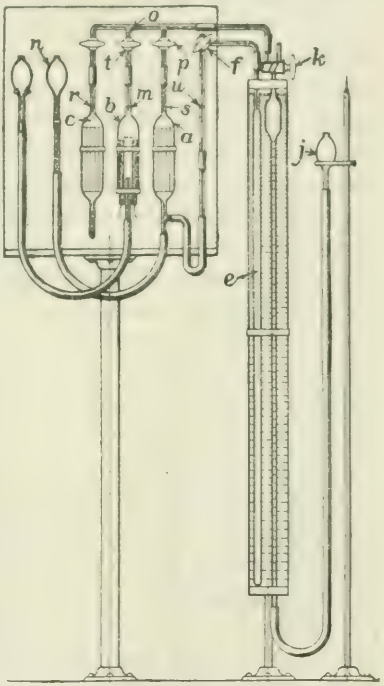

FIGURE 1.—Laboratory form of apparatus for the exact analysis of mine air.

GAS-ANALYSIS APPARATUS.

The apparatus used by the authors of this report in making the analyses herein reported are designated as A and B. Apparatus A, shown in figure 1, is slightly modified from that designed by Haldane.[d] It is fully described in Bulletin 42 of the Bureau of Mines.[e] It consists of a 21-c. c. burette with a bulb at the top having a capacity of 15 c. c. and a stem having a capacity of 6 c. c. The stem is graduated in 0.01 c. c. The apparatus has three pipettes, of which *a* contains potassium hydroxide, and *c* alkaline pyrogallate; *b* is the slow-combustion pipette. The sample is measured in the burette against the air in the compensating tube *e*, by bringing the columns of potassium hydroxide solution in *a* and *u* exactly to the

[a] Bowen, David, and French, W. E., Safety devices, in connection with electrical machinery, for coal mines: Coll. Guard., vol. 103, 1912, p. 1136.

[b] Parr, S. W., and Barker, P., Occluded gases in coal: Univ. Illinois Bull. 32, vol. 6, 1909, 28 pp.

[c] Harger, John, Chemistry applied to coal mining: Jour. Soc. Chem. Ind., vol. 32, 1913, No. 9, p. 460.

[d] Foster, C. Le N., and Haldane, J. S., The investigation of mine air, 1905, p. 101.

[e] Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, pp. 17, 18. (In press.)

marks shown thereon, leaving the stopcocks p and k so that communication is made between the burette and potassium hydroxide solution. Subsequent readings are made in the same manner.

The carbon dioxide is removed from the sample by passing the latter back and forth three or four times between the burette and the potassium hydroxide solution. After the contraction in volume caused by the removal of the carbon dioxide has been recorded, the sample is passed into the slow-combustion pipette. The platinum wire in that pipette is heated to a white heat by a current of about 5 amperes for about 2 minutes, when the methane in the sample will be entirely burned. The pipette is then cooled, preferably by playing a blast of compressed air upon it, and the sample is transferred to the burette to measure the contraction in volume produced by the burning of the methane. The sample is next passed into the potassium hydroxide pipette to absorb the carbon dioxide produced by the combustion. The volume of the carbon dioxide absorbed is measured by transferring the sample to the burette again and finally, if the oxygen content of the sample is desired, the sample is passed into the alkaline pyrogallate pipette and the contraction in volume after the absorption of oxygen is determined by again measuring the sample in the burette. By analyzing another portion of the mixture for oxygen, the volume of the oxygen consumed by the burning of the methane can be determined, and this volume added to the volume determined by the first absorption gives the total oxygen content of the sample as received.

At the beginning of a determination the free capillary spaces in the apparatus are filled with nitrogen left from a previous analysis, so that there may be no complications from the presence of a gas not in the sample to be analyzed. The mercury in the burette is never raised above the point, but all the sample is brought in contact with the reagents and with the slow-combustion coil by passing it back and forth a number of times for each absorption and for the combustion.

The apparatus just described is not suitable for analyzing some mine atmospheres because the contraction after burning would cause the mercury to rise to the ungraduated part of the tube where readings could not be made, or the mixture might contain so much methane that an explosion would result were it passed directly into the combustion pipette; hence for this class of samples the apparatus shown in figure 2, and designated on the following pages as B, was used.

This apparatus, which is described in Bulletin 42,[a] has a 100-c. c. burette graduated in 0.1 c. c., and seven pipettes, a, b, c, d, e, f, and i.

[a] Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, p. 42. (In press.)

a contains potassium hydroxide; *b* and *i*, alkaline pyrogallate; *c*, fuming sulphuric acid; *d* and *e*, cuprous chloride; *f* is the slow-combustion pipette. The pipette *i* is kept filled with nitrogen prepared by removing oxygen from ordinary air.

Before an analysis is begun a few cubic centimeters of the nitrogen in *i* is drawn into the burette and then turned into the air. This procedure removes from the horizontal capillary tubing *p* any oxygen that may have been left therein from a previous determination. The sample of gas is drawn into the burette through the 3-way stopcock *g*, and is measured against the pressures of the air confined in the

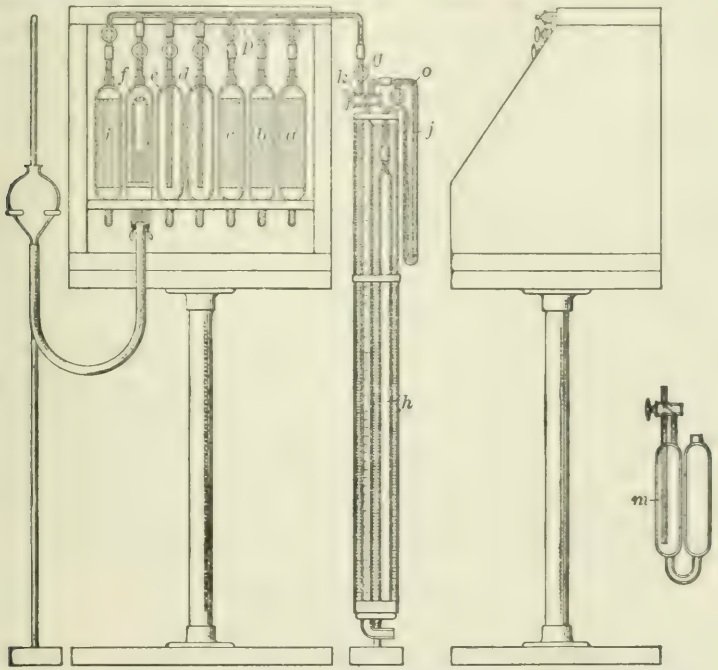

FIGURE 2.—Apparatus for mixtures containing CO_2, C_2H_4, O_2, CO, H_2, CH_4, and N_2O.

compensating tube *h* by bringing the mercury in the manometer tube exactly to the mark *j*.

Samples containing much methane are handled in the following manner:

The carbon dioxide and oxygen are absorbed, the residual gas is passed into the slow-combustion pipette, and the platinum wire therein is heated to a white heat. Sufficient oxygen to burn the methane is then measured in the burette and slowly passed into the combustion pipette at the rate of about 10 c. c. per minute. In this manner the methane burns as fast as the oxygen enters, and an

explosion that might shatter the pipette can not follow. Two trials may be required to determine the proper amount of oxygen for burning the methane in an unknown mixture and yet have the sample as large as possible.

With apparatus A (fig. 1) differences in volume of the gas in the burette as small as 0.003 c. c. can be measured and with apparatus B (fig. 2) differences of 0.1 c. c. The burette readings with the latter apparatus were carried to two decimal places each time, but the results are not significant below 0.05 per cent. If the contraction and the carbon dioxide found agree closer than this it can be considered a coincidence. An allowance of 0.10 per cent for experimental error was made for any burette reading. These errors of experimentation being granted, then in none of the analyses shown later would one be justified in making a calculation for any other combustible gas than methane, nor could one be absolutely sure that he was right in reporting such a gas.

In the case of one of the analyses of sample No. 2164, for instance, the contraction in volume due to combustion was 0.954 c. c. and the volume of carbon dioxide was 0.481 c. c. If theoretically correct according to the methane reaction, the volume of carbon dioxide reading should be either one-half of the contraction, or 0.477, or the contraction should be 0.962 (0.006 c. c. greater than that obtained), or twice the carbon dioxide reading. Were the volume of carbon dioxide 0.477 (0.004 c. c. less) it would correspond to the observed contraction. Were the contraction 0.002 c. c. greater, or 0.956 c. c., and the volume of carbon dioxide 0.003 c. c. less, or 0.478 c. c., the theoretical condition would be satisfied and the analysis would still be correct within the experimental error of the apparatus.

MINE-AIR ANALYSES.

In the table that follows are shown analyses of samples of mine air collected from 44 mines situated in 12 States. Most of the samples were collected by mining engineers of this bureau. Some samples were collected in moving air, but the velocity of the air was not recorded. In such cases the column headed "Volume of air current" has been left blank. In those cases where the air is said to be "still" its velocity was not sufficient to move the vanes of an anemometer.

In the case of those mixtures in which the carbon dioxide produced by the combustion had a greater partial pressure than 200 mm. a correction has been applied in the reaction for methane and oxygen.

The data recorded in one analysis are presented herewith. They show the procedure in using the apparatus illustrated by figure 1.

Recorded data in the analysis of sample 2547, from an anthracite mine in Luzerne County, Pa.

	c. c.
Volume of air current, 18,150 cubic feet per minute.	
Volume taken for analysis	20.029
Volume after absorption of CO_2	20.015
Volume of CO_2 absorbed	.014
Volume taken for combustion	20.015
Volume after burning	19.479
Contraction in volume due to burning	.536
Volume after absorption of CO_2	19.211
Volume of CO_2 absorbed	.268

From the above data the CO_2 and CH_4 originally present in the sample are calculated as shown below, the percentage of methane being calculated from the volume of carbon dioxide produced by combustion.

$$CO_2=\frac{0.014}{20.029}\times 100=0.07 \text{ per cent.}$$

$$CH_4=\frac{0.268}{20.029}\times 100=1.34 \text{ per cent.}$$

It will be noticed that the contraction after combustion bears a ratio to the carbon dioxide produced by combustion of 2 to 1. There are combinations of combustible gases (not including methane) that if present in a gas mixture would produce a ratio of 1 to 2 between the volume of carbon dioxide and the contraction after burning, but the nature of these gases and their combinations are against their occurring in normal mine air. For instance, a mixture of equal volumes of carbon monoxide and hydrogen, or a mixture that contained ethylene and hydrogen in the ratio of 3 volumes of ethylene to 4 volumes of hydrogen would, on combustion, produce a volume of carbon dioxide equal to one-half the contraction. In analyzing many samples of mine gases the authors determined the volume of oxygen consumed in burning the methane. This procedure, which in the case of normal mine air always resulted in showing that the oxygen consumed in burning the methane is equal to twice the carbon dioxide produced and is equal to the contraction, removed all doubt as to the identity of the combustible gas. Hydrogen or ethylene in mine air (in proportions other than those first mentioned) would immediately show up in the combustion data, and if they occur at all they should certainly occur much more frequently in some of the many other possible proportions than in those mentioned above.

The absence of any appreciable proportion of carbon monoxide is also demonstrated by the fact that normal mine air has not the poisonous effects that would be caused by the presence of even minute proportions of carbon monoxide.

TABLE 1. *Samples of mine air examined and results of the examination.*

Number of sample.	State.	County.	Designation of mine.	Kind of coal.	Apparatus used.	Volume of air current.	CO_2 in sample.	CH_4 in sample.	Volume taken for analysis.	Contraction after combustion.	CO_2 from combustion.
						Cu. ft. per min.	*P. ct.*	*P. ct.*	*C. c.*	*C. c.*	*C. c.*
2537	Pennsylvania	Luzerne	1	Anthracite	A	18,100	0.07	1.34	20.029	0.536	0.268
2537	do	do	1	do	A	18,100	.07	1.34	20.284	.539	.271
2654	do	do	1	do	A	25,760	.07	1.16	20.345	.475	.236
2642	do	do	1	do	A	178,560	.09	.76	20.000	.306	.151
2642	do	do	1	do	A	178,560	.09	.78	20.000	.318	.156
2641	do	do	1	do	A	90,000	.06	1.01	20.198	.416	.204
2641	do	do	1	do	A	90,000	.05	1.04	20.000	.421	.208
2643	do	do	1	do	A	140,344	.08	.35	20.286	.144	.071
2643	do	do	1	do	A	140,344	.08	.37	20.000	.139	.074
2165	do	do	2	do	A	(*a*)	.04	.02	20.015	.013	.005
2165	do	do	2	do	A	(*a*)	.05	.04	20.181	.012	.009
2164	do	do	2	do	A	(*a*)	.05	2.34	20.329	.959	.475
2164	do	do	2	do	A	(*a*)	.07	2.37	20.304	.954	.481
2176	do	do	3	do	A	44,200	.04	1.57	20.010	.627	.315
2176	do	do	3	do	A	44,200	.02	1.60	20.183	.639	.322
2657	do	Lackawanna	4	do	A	28,764	.33	.52	20.110	.206	.104
2657	do	do	4	do	A	28,764	.30	.50	20.035	.212	.100
2655	do	do	4	do	A	21,000	.28	.76	19.990	.300	.152
2655	do	do	4	do	A	21,000	.27	.75	20.020	.304	.150
2640	do	Luzerne	5	do	A	17,136	.13	1.27	20.087	.510	.255
2640	do	do	5	do	A	17,136	.10	1.27	20.032	.513	.255
2639	do	do	5	do	A	60,060	.16	2.29	20.091	.924	.460
2647	do	do	5	do	A	23,760	.14	2.20	20.100	.882	.440
2647	do	do	5	do	A	23,760	.13	2.19	20.151	.882	.439
2650	do	do	5	do	A	13,600	.17	3.06	20.195	1.24	.617
2650	do	do	5	do	A	13,600	.16	3.05	20.041	1.222	.610
2644	do	do	6	do	A	4,830	.18	1.25	19.998	.509	.251
2298	Illinois	Williamson	7	Bituminous	A	36,190	.24	.14	20.143	.060	.028
2298	do	do	7	do	A	36,190	.24	.13	20.075	.051	.027
2308	do	do	7	do	A	41,580	.35	.21	19.982	.080	.042
2308	do	do	7	do	A	41,580	.37	.20	19.654	.075	.040

2304	do	do	8	do	A	54,225	.05	.09	20.020	.037	.018
2304	do	do	8	do	A	54,225	.06	.10	19.982	.040	.020
2330	do	do	9	do	A	16,240	.37	.21	19.863	.080	.041
2330	do	do	9	do	A	16,240	.34	.20	19.800	.077	.040
2329	do	do	9	do	A	13,650	.44	.19	20.120	.077	.038
2329	do	do	9	do	A	13,650	.44	.18	20.120	.077	.037
2301	do	do	10	do	A	23,870	.05	.00	20.040	.000	.000
2301	do	do	10	do	A	23,870	.05	.01	19.956	.005	.002
2299	do	Jackson	11	do	A	30,800	.05	.02	19.905	.008	.003
2297	do	do	11	do	A	55,300	.11	.04	20.097	.019	.009
2297	do	do	11	do	A	55,300	.11	.05	20.096	.018	.010
2295	do	do	12	do	A	20,844	.31	.00	20.081	.000	.000
2295	do	do	12	do	A	20,844	.30	.00	19.882	.000	.000
2303	do	Franklin	13	do	A	90,396	.05	.03	19.942	.014	.005
2303	do	do	13	do	A	90,396	.05	.03	19.978	.013	.006
2323	do	do	13	do	A	64,288	.10	.24	20.230	.100	.049
2323	do	do	13	do	A	64,288	.10	.23	19.900	.097	.045
2322	do	do	14	do	A	6,000	.10	.35	19.966	.147	.070
2227	Colorado	Fremont	15	do	A	(a)	.19	.34	20.445	.139	.070
2229	do	do	15	do	A	(a)	.29	.41	20.674	.173	.084
2134	do	Las Animas	16	do	A	27,090	.05	.21	20.070	.080	.042
2134	do	do	16	do	A	27,090	.06	.20	20.050	.077	.040
2130	do	do	16	do	A	5,022	.07	.36	19.980	.141	.072
2130	do	do	16	do	A	5,022	.06	.36	20.020	.138	.072
1654	do	do	17	do	A	(a)	1.34	.13	20.000	.055	.026
1638	West Virginia	McDowell	18	do	A	14,000	.05	.88	20.192	.364	.178
1638	do	do	18	do	A	14,000	.06	.84	20.343	.342	.172
1829	do	do	19	do	A	(a)	.05	.45	20.320	.190	.092
1831	do	do	19	do	A	(a)	.03	.56	20.425	.236	.116
1831	do	do	19	do	A	(a)	.04	.58	20.342	.241	.117
1835	do	do	19	do	A	(a)	.06	.90	20.262	.368	.182
1835	do	do	19	do	A	(a)	.05	.89	20.230	.370	.180
1627	do	Mineral	20	do	A	(a)	.28	.61	20.393	.251	.124
1630	do	do	20	do	A	(a)	.30	.36	20.403	.146	.074
1583	Alabama	Jefferson	21	do	A	(a)	.10	1.07	20.214	.434	.218
1791	do	do	21	do	A		.24	.21	20.230	.085	.043
1791	do	do	21	do	A		.20	.20	20.321	.085	.041

[a] Still.

TABLE 1.—*Samples of mine air examined and results of the examination*—Continued.

Number of sample.	State.	County.	Designation of mine.	Kind of coal.	Apparatus used.	Volume of air current.	CO_2 in sample.	CH_4 in sample.	Volume taken for analysis.	Contraction after combustion.	CO_2 from combustion.
						Cu. ft. per min.	*P. ct.*	*P. ct.*	*C. c.*	*C. c.*	*C. c.*
1745	Alabama	Jefferson	21	Bituminous			0.05	0.20	20.401	0.090	0.042
1745	do	do	21	do	A		.06	.22	20.340	.089	.045
1747	do	do	21	do	A		.07	.21	20.425	.087	.043
1747	do	do	21	do	A		.07	.21	20.400	.088	.044
1794	do	do	21	do	A		.04	.43	20.262	.169	.088
1794	do	do	21	do	A		.05	.42	20.264	.178	.086
1661	do	Tuscaloosa	22	do			.49	2.39	20.310	.980	.487
1661	do	do	22	do	A	(a)	.49	2.41	20.510	.992	.495
1660	do	do	22	do	A	(a)	.69	3.82	20.280	1.555	.776
1660	do	do	22	do	A	(a)	.67	3.78	20.121	1.525	.760
2671	do	Bibb	23	do	A	(a)	.59	3.06	20.085	1.231	.614
2671	do	do	23	do	A	(a)	.55	3.04	20.079	1.229	.610
2670	do	do	23	do	A	(a)	.58	3.29	20.000	1.307	.653
2669	do	do	23	do	B	(a)	.51	13.07	49.00	12.65	6.40
1542	do	Jefferson	24	do	A	45,926	.05	.26	19.926	.100	.048
1380	Oklahoma	Pittsburg	24	do	B	(a)	.24	18.61	53.21	19.77	9.90
1381	do	do	24	do	B	(a)	.27	19.20	48.49	18.65	9.31
1411	do	do	25	do	A	(a)	.05	.92	19.443	.357	.179
1412	do	do	25	do	A	28,400	.20	.17	19.627	.063	.032
1439	Kansas	Cherokee	26	do	B	(a)	1.14	13.01	61.10	15.95	7.95
1439	do	do	26	do	B	(a)	.92	12.89	54.30	14.35	7.00
1440	do	do	26	do	B	(a)	.28	4.73	52.85	5.00	2.50
1458	do	do	26	do	B	(a)	.60	4.15	66.20	5.50	2.75
1463	do	do	26	do	B	(a)	.54	6.71	64.80	8.90	4.35
1641	New Mexico	Colfax	27	do		(a)	.26	1.84	20.675	.760	.380
1641	do	do	27	do	A	(a)	.20	1.83	20.500	.755	.375
2046	Kentucky	Muhlenberg	28	do	A	18,000	.62	.14	20.010	.050	.028
2046	do	do	28	do	A	18,000	.61	.14	20.070	.050	.028
2045	do	do	28	do	A	8,000	.60	.26	20.030	.107	.053
2043	do	do	28	do	A	7,875	.56	.18	20.082	.070	.037
2043	do	do	28	do	A	7,875	.50	.18	20.030	.075	.037

1806	Pennsylvania	Jefferson	29	do		(a)	.49	1.15	20.410	.470	.235
1776	do	do	29	do	A	(a)	.07	.44	20.415	.180	.090
1804	do	do	30	do	B	(a)	.15	24.62	98.50	48.60	24.25
1804	do	do	30	do	B	(a)	.18	24.59	82.70	41.00	20.35
1819	do	do	30	do	B	(a)	.36	19.15	55.10	21.05	10.55
1819	do	do	30	do	B	(a)	.36	19.40	55.40	21.35	10.75
1348	do	Washington	31	do	A	12,000	.10	.74	19.768	.300	.146
1348	do	do	31	do	A	12,000	.10	.74	19.819	.298	.146
1349	do	do	31	do	A	11,250	.72	.71	19.515	.279	.139
2087	Indiana	Sullivan	32	do	A	8,400	.15	.28	20.025	.113	.056
2088	do	do	32	do	B	(a)	.59	6.08	51.00	6.4	3.1
1440	Missouri	Lafayette	33	do	B	(a)	.36	8.53	55.10	9.60	4.70
1436	Washington	Kittitas	34	do	A	1,600	.06	1.28	20.913	.538	.267
1436	do	do	34	do	A	1,600	.07	1.33	20.362	.553	.270
1320	Wyoming	Uinta	35	do	A	(a)	.53	2.47	19.902	.991	.493
1320	do	do	35	do	A	(a)	.55	2.54	19.499	.990	.496
2819	West Virginia	Marshall	36	do	B	(a)	.72	5.21	49.90	5.15	2.60
2819	do	do	36	do	B	(a)	.68	5.07	51.30	5.20	2.60
2829	do	do	36	do	A	1,800	.10	.19	19.945	.075	.038
2829	do	do	36	do	A	1,800	.10	.18	19.890	.075	.037
2835	do	do	36	do	A	(a)	.15	.53	20.020	.215	.107
2835	do	do	36	do	A	(a)	.14	.52	20.030	.212	.105
2781	Oklahoma	Pittsburg	37	do	B	(a)	6.82	28.25	40.35	22.00	11.40
2781	do	do	37	do	B	(a)	7.07	28.33	41.65	23.55	11.80
2779	do	do	37	do	B	(a)	1.96	7.47	50.90	7.55	3.80
2779	do	do	37	do	B	(a)	2.03	7.26	51.70	7.55	3.75
2411	Pennsylvania	Luzerne	38	Anthracite	B	(a)	.10	6.06	49.50	6.10	3.00
2543	do	do	39	do	B	(a)	.20	33.2	48.8	32.7	16.2
2424	do	do	40	do	B	(a)	.10	17.35	49.55	17.4	8.6
2419	do	do	42	do	B	(a)	.40	13.86	50.5	14.0	7.0
2481	do	do	43	do	B	(a)	.10	33.46	50.5	33.8	16.9
2615	Kentucky	Hopkins	44	Bituminous	B	(a)	.33	22.25	51.67	23.40	11.55
2615	do	do	44	do		(a)	.37	22.29	54.30	24.60	12.10
2614	do	do	44	do	B	(a)	.38	7.89	51.95	8.15	4.10
2614	do	do	44	do		(a)	.34	8.08	50.17	8.08	4.05

a Still.

Some mine-gas samples that were collected in mines into which natural gas had leaked from wells have not been included in the tables, the object of this report being to show the combustible gas coming from the coal strata.

The leakage of natural gas from wells driven to gas sands below the coal strata is known to have caused three explosions in coal mines.[a] Old abandoned wells are especially a menace to coal miners, because their exact situation may not be known and miners may break old casings in the development of a mine. Accidents caused by leakage of natural gas have happened even where a large pillar of coal surrounded the casing of a well. The natural gas found in the United States seems to consist of paraffin hydrocarbons mixed with small proportions of carbon dioxide and nitrogen. In a few samples that have been collected methane was the only paraffin hydrocarbon present, but the great majority of samples contained methane mixed with small proportions of ethane and, undoubtedly, with traces of still higher members of the paraffin series. The natural gas used at Pittsburgh, which comes from different wells in western Pennsylvania and West Virginia, contains about 83.1 per cent methane, 16 per cent ethane, 10.9 per cent nitrogen, and a trace, less than 0.10 per cent, of carbon dioxide. From their study of the gas the authors came to the conclusion that it did not differ materially from methane as regards explosibility; hence there would seem to be little or no reason for regarding this natural gas as more dangerous than methane.

Below are given the explosive limits, as determined by the writers, of this natural gas and air and the explosive limits of methane and air:

	Low limit.	High limit.
Methane	5.5	12.8
Natural gas	5.0	11.6

These values were determined by confining the mixtures in a Hempel explosion pipette over mercury and igniting them with an electric spark from an induction coil. With the percentages of gas stated, the flame passed through every part of the mixture. Under the stated conditions of the experiment, no appreciable flash could be observed with leaner mixtures, although visible inflammation occurs below these limits when a means of ignition stronger than a small spark is used.

Dixon and Howard[b] obtained the following ignition temperatures of ethane and methane mixed with air: Methane, 650 to 750° C.; ethane, 520 to 630° C.

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[a] Rice, G. S., and Hood, O. P., Oil and gas wells through workable coal beds; papers and discussions: Bull. 65, Bureau of Mines, 1913, 101 pp.

[b] Dixon, H. B., and Howard, C., The ignition temperature of gases: Chem. News, vol. 99, 1909, p. 139.

The danger to miners from natural gas lies in the sudden irruption of a large body of the gas into a mine. The authors are analyzing samples of mine air from mines near gas wells in order to determine if there is any influx of natural gas, and to warn the management of the mines. It is believed that the presence of other paraffin hydrocarbons than methane in the air of mines near natural-gas wells will indicate some leakage from the wells.

As regards the presence of carbon monoxide in what may be termed normal mine air—that is, mine air not contaminated by the after damp from an explosion or the gases from a mine fire—analyses with the apparatus shown in figure 1 demonstrated the gas was not present in a large number of samples of such mine air in quantities greater than 0.01 or 0.02 per cent, the limits of accuracy of the apparatus.

The study of the nature of the inflammable gases in coal mines is being extended to include more mines than are represented in this paper.

CONCLUSION.

The authors present this study as showing that normal mine-air samples obtained from many mines in different parts of this country contain only methane as the combustible gas. The authors believe that it has not as yet been fully demonstrated that gases other than methane may be constituents of normal mine air except possibly in rare cases.

PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF MINING.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls., 4 figs.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 44. First national mine-safety demonstration, Pittsburgh, Pa., October 30 and 31, 1911, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 7 pls., 4 figs.

BULLETIN 45. Sand available for filling mine workings in the Northern Anthracite Coal Basin of Pennsylvania, by N. H. Darton. 1912. 32 pp., 8 pls., 5 figs.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 56. First series of coal-dust explosion tests in the experimental mine, by G. S. Rice, L. M. Jones, J. K. Clement, and W. L. Egy. 1913. 115 pp., 12 pls., 28 figs.

BULLETIN 65. Oil and gas wells through workable coal beds; papers and discussions, by G. S. Rice, O. P. Hood, and others. 1913. 101 pp., 1 pl., 11 figs.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions; report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.

TECHNICAL PAPER 24. Mine fires; a preliminary study, by G. S. Rice. 1912. 51 pp., 1 fig.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.

TECHNICAL PAPER 29. Training with mine-rescue breathing apparatus, by J. W. Paul. 1912. 16 pp.

TECHNICAL PAPER 32. The cementing process of excluding water from oil wells, as practiced in California, by Ralph Arnold and V. R. Garfias. 1913. 12 pp., 1 fig.

TECHNICAL PAPER 40. Metal-mine accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 54 pp.

TECHNICAL PAPER 46. Quarry accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 32 pp.

TECHNICAL PAPER 47. Portable electric mine lamps, by H. H. Clark. 1913. 13 pp.

TECHNICAL PAPER 48. Coal-mine accidents in the United States, 1896–1912, with monthly statistics for 1912, compiled by F. W. Horton. 1913. 74 pp., 10 figs.

TECHNICAL PAPER 53. Proposed regulations for the drilling of gas and oil wells, with comments thereon, by O. P. Hood and A. G. Heggem. 1913, 28 pp., 2 figs.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp., 5 figs.

MINERS' CIRCULAR 5. Electrical accidents in mines; their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsey, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 9. Accidents from falls of roof and coal, by G. S. Rice. 1912. 16 pp.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1912. 14 pp.

MINERS' CIRCULAR 11. Accidents from mine cars and locomotives, by L. M. Jones. 1912. 16 pp.

MINERS' CIRCULAR 12. The use and care of miners' safety lamps, by J. W. Paul. 1913. 16 pp., 4 figs.

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